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Update article

The Muscle Sensor for on-site neuroscience lectures to pave the way for a better understanding of brain–machine-interface research

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ABSTRACT

Neuroscience is an expanding field of science to investigate enigmas of brain and human body function. However, the majority of the public have never had the chance to learn the basics of neuroscience and new knowledge from advanced neuroscience research through hands-on experience. Here, we report that we produced the Muscle Sensor, a simplified electromyography, to promote educational understanding in neuroscience. The Muscle Sensor can detect myoelectric potentials which are filtered and processed as 3-V pulse signals to shine a light bulb and emit beep sounds. With this educational tool, we delivered "On-Site Neuroscience Lectures" in Japanese junior-high schools to facilitate hands-on experience of neuroscientific electrophysiology and to connect their text-book knowledge to advanced neuroscience researches. On-site neuroscience lectures with the Muscle Sensor pave the way for a better understanding of the basics of neuroscience and the latest topics such as how brain–machine-interface technology could help patients with disabilities such as spinal cord injuries.

1. Introduction

Recently, brain science or neuroscience has become a popular area of interest to the general public. However, it is concerning there are a growing number of pseudoscience on the brain which have become equally as popular (OECD, 2007), most likely because the majority of the public have never had the chance to learn the basics of neuroscience to be able to tell the difference. In fact, only a small number of people, such as students in medical or co-medical schools, have the opportunity to study neuroscience in Japan. These individuals are usually university or graduate school students who have studied physiology or medicine, and it is the reason why fields like neuroscience have remained a specialized area.

Although only a small group of people study neuroscience in school, young teenagers today do have the chance to learn the basics during junior high school, such as the body kinetics to explain how animals move their bodies, which is a fundamental aspect of neuroscience. In fact, according to the 2012 junior high school curriculum guidelines by the Japanese government (MEXT, 2010), students should learn about animal body shapes and how they are designed to move. Following the guidelines, the basics of neuroscience is also mentioned in the current junior high school science text book, under a section called "How Muscles Work", which includes a diagram showing how an electrical signal is sent to a muscle after traveling from the brain to the spinal cord, and through the motor neurons. Although the same guidelines recommend that students conduct experiments in order to understand how animals move their bodies, there is little know-how to conduct hands-on experiment in a school environment. In order to study bioelectric signals created by muscles, teachers would need to bring medical devices or hospital equipments capable of measuring myoelectric potentials. However, because it is difficult to get hold of, most students are confined to reading textbooks in the classroom when it comes to learning about the basic concept of neuroscience.

Our aim is to improve neuroscience literacy among junior high school students by visiting their schools to give on-site neuroscience lectures. We developed a simplified device, the Muscle Sensor, a portable myoelectric potential detector which detects the electric signal created by muscle movement. Junior high school students used the Muscle Sensor to learn how their muscle works via hands-on experience during on-site neuroscience lectures.

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2. Materials and methods

2.1. The design of "Muscle Sensor"

The Muscle Sensor is a portable myoelectric potential detector developed in the National Institute for Physiological Sciences. By connecting the device with electrodes on an examinee's skin, the Muscle Sensor detects bioelectrical signals, or electric potentials created by moving muscles. These can be converted into 3-volt pulsing signals, and then finally lights up a small light bulb or makes a piezoelectric alarm go off. Unlike conventional medical devices which output the muscle's potential waveform directly, this device's main feature is that it converts the electrical potentials into 3-volt pulse signals. Since it eliminates the need for large complicated waveform analysis systems, the Muscle Sensor is easy to carry around. The Muscle Sensor would not be used in a hospital since it was not designed to study muscles for diagnosis.

2.2. The circuit diagram and signal waveforms

The circuit diagram and signal waveforms in different parts of the device are shown in Figs. 1 and 2. The Muscle Sensor's circuit diagram can be separated into six different parts, each of which play a key role as described in detail below.

2.2.1. Electrodes

Electrodes placed on the examinee's skin detect muscle's electric potentials, or myoelectric potentials. In order to detect these signals, the Muscle Sensor uses a bipolar method with three electrodes; two measuring electrodes and one indifferent electrode. The average amplitude of electrical potentials is usually between a few μV to a few mV, and the frequency component is between a few Hz to a few 100 kHz.

2.2.2. Amplifier

A highpass filter (cutoff frequency: 1 Hz) is used to separate away any DC current or low-frequency components from the electrode's myoelectric potential waveform before the signals' impedance conversion is carried out using a voltage follower. Afterwards, the signals are amplified to sixty times by using a differential amplifier, and then passed through a highpass filter (cutoff frequency: 100 Hz). Then, the signals are amplified again to seven times by using an inverting amplifier. Finally, all remaining low-frequency components are removed by using an active filter (cutoff frequency: 100 Hz).

2.2.3. Signal smoothing filter

The full-wave rectifier was used to invert the negative potentials included in the input, and to add to the original positive potentials included in the input. The signal waveform is more smoothed out by using a smoothing condenser.

2.2.4. Threshold control

A comparator circuit is used to determine whether the input voltage is smaller or bigger than the reference voltage. The reference voltage is set as 1.2 V. If the input voltage goes above 1.2 V, the saturated power voltage (approximately 3 V) is output. Additionally, the amplitudes of incoming signals can be adjusted using a variable resister.

2.2.5. Output

When the signals go over the threshold value, a transistor driver circuit makes the built-in LED light flash, and the output voltage becomes 3 V. Instead of creating a myoelectric potential waveform, these components make it possible for the Muscle Sensor to produce 3-volt pulse signals which can light up an external light bulb (see Fig. 3).

2.2.6. Power source

Four 1.5 V AA batteries and a ±3 V power source.

3. Results

3.1. How we teach: using the Muscle Sensor in an on-site neuroscience lecture

To pave the way for a better understanding of body function and brain machine interfaces, we conducted on-site neuroscience lectures using the "Muscle Sensor" in junior high schools.

An on-site lecture (for 45 min) carried out at a junior high school had covered the following parts:

Lesson Part 1 First, the students were taught how our brain works in general.

Lesson Part 2 Then, the students were taught that the nervous system is made up of neurons, and that the electrical signals generated in neurons go through nerves. In this part, the shape of neurons and the electrical signal that neurons generate were also learned.

Lesson Part 3 Afterwards, the students were taught that when they move their bodies, an electrical signal is sent from the brain (cerebral cortex), through the spinal cord, and through the motor neurons until it finally reaches the muscles. Then, the students were asked to try out the Muscle Sensor to experience for themselves how the electrical signal they generate can be used to move muscles. Here, the difference of neural electrical signals from electrical myogram that the Muscle Sensor can detect was also learned.

Lesson Part 4 Finally, the on-site lecturer introduced a number of the latest neuroscience researches being carried out, including brain–machine-interface researches.

The majority of the students in their second year of junior high school should have already learned about the topics of Lesson Part 3, since it is already included in the MEXT curriculum guidelines (MEXT, 2010). However, as stated in the introduction, most of these lessons are restricted to classroom deskwork. The Muscle Sensor made it possible to learn about the topic through hands-on experience.

To use the Muscle Sensor effectively in Lesson Part 3, usually (i) one or two students were asked to help carry the demonstration, followed by (ii) free time where all of the students could try out the device. The best place to detect a myoelectric potential signal was on the forearm or bicep. During the demonstration, the students were taught how to attach the electrodes to the skin, how to use the Muscle Sensor, and how to tell the difference between a bioelectric signal and noise. The light bulb was a good visual indication for the students, and showed them that when they used their muscles, the muscles produced electrical signals to shine a light bulb (Fig. 3). Following the demonstration, a Muscle Sensor device was passed around smaller groups, and the students could test their own muscle. Overall, the students were able to learn how myoelectric potential can be generated from any muscle throughout the body. The Muscle Sensor could also be connected to a simple robotic arm, and the students could try controlling the arm using their muscles (Fig. 3).

In regards to Lesson Part 4, the students were given an update on the latest neuroscience research, particularly those which used the same principles as what the students had just learned about. The best example was brain–machine interface research, which has significant medical applications. For example, robotic arms or legs

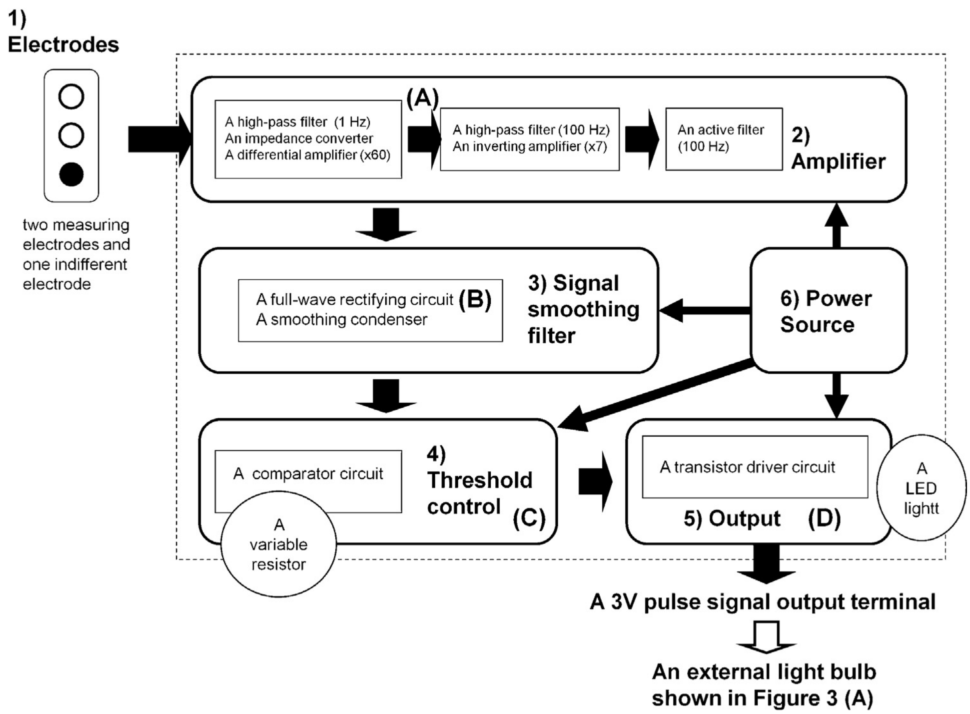

Fig. 1. The circuit diagram of the Muscle Sensor. The Muscle Sensor's circuit diagram can be separated into six different parts as described in the text. The signal waveforms at (A)–(D) are shown in Fig. 2.

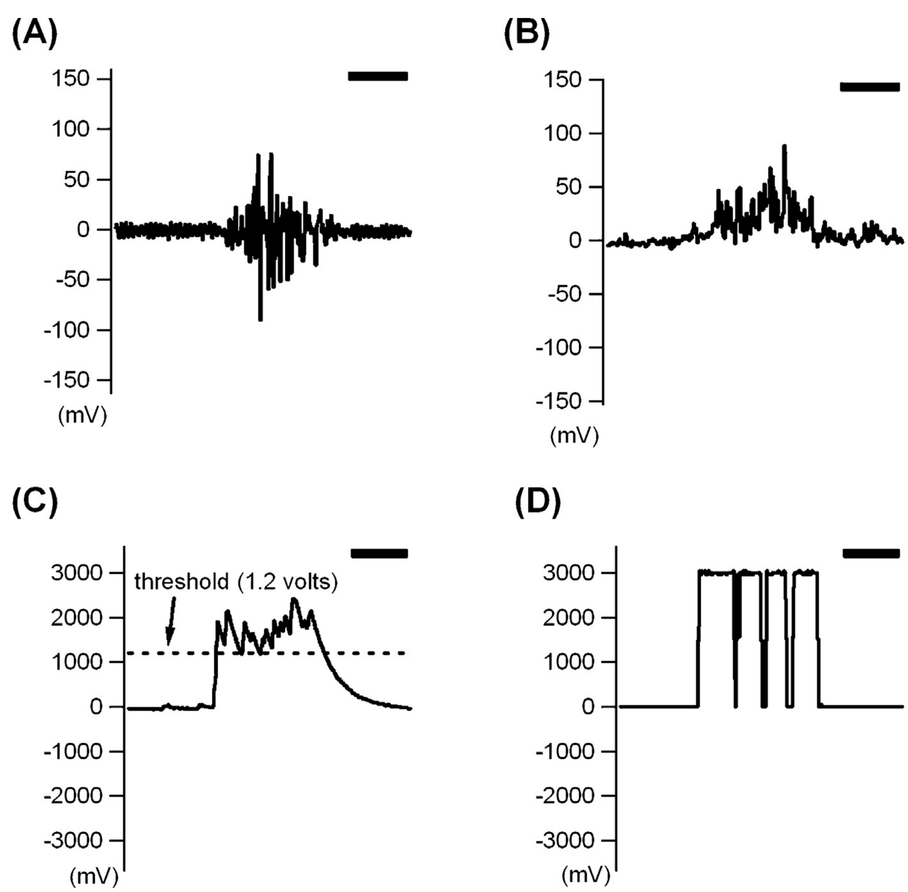

Fig. 2. Signal waveforms at different parts of the Muscle Sensor.
The signal waveforms at (A)–(D) in Fig. 1 are shown. *Note*: These waveforms are different signals. Scale bars indicate 500 ms. (A) A signal waveform after processed at a differential amplifier of the amplifier. (B) A signal waveform after processed at a full-wave rectifying circuit of the signal smoothing filter. (C) A signal waveform at a comparator circuit of the threshold control. The threshold is set as 1.2 V. (D) A signal waveform at the output.

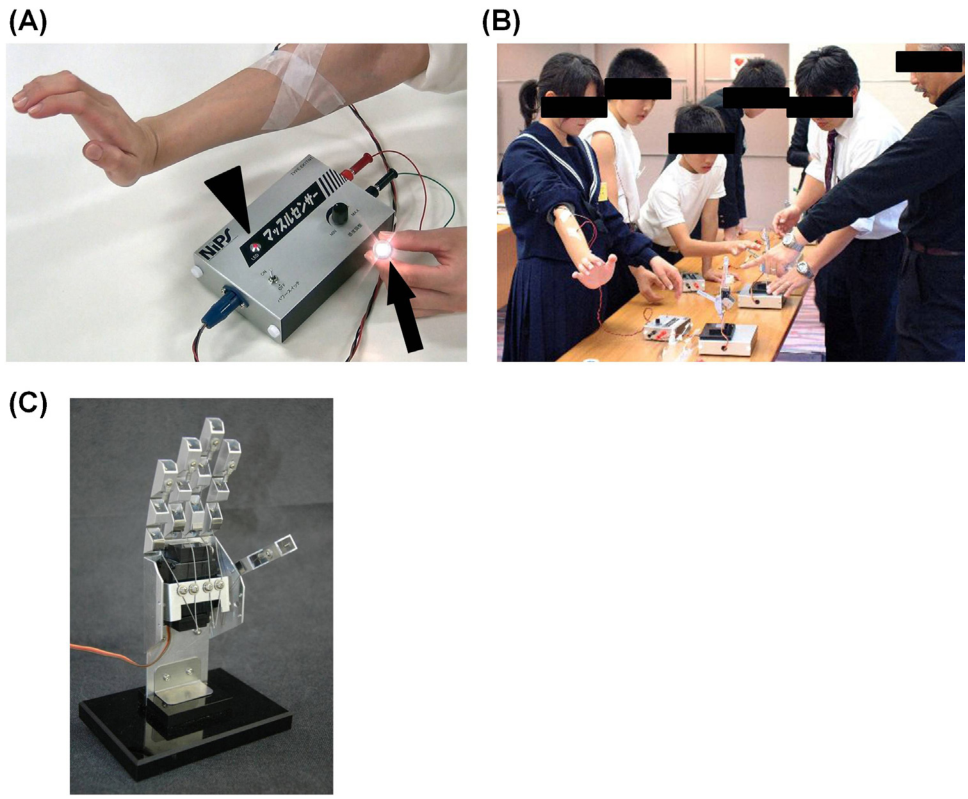

Fig. 3. Students trying out the Muscle Sensor. On-site neuroscience lectures were carried out at all 19 junior high schools in Okazaki city, Aichi prefecture, Japan, between 2009 and 2011. (A) The Muscle Sensor can detect myoelectric potentials which are filtered and processed as 3-volt pulse signals to shine a light bulb. An arrow indicates an external light bulb. An arrow head indicates a LED light. (B) The output of the Muscle Sensor was connected to the simple robotic arm controller. (C) The robotic arm used in (B).

capable of being controlled using bioelectric signals coming from brain or muscles would help patients with disabilities such as spinal cord injuries using artificial arms or legs (Hochberg et al., 2012), and patients with hearing disabilities would be able to regain hearing ability using cochlear implants capable of sending out electrical signals that the brain could process (Clark, 2003).

Students found it easier to understand how a robotic arm could be controlled using bioelectric signals because they had experienced their own bioelectric signals turning on a light bulb by using the Muscle Sensor.

3.2. Neuroscience understanding with on-site lectures

On-site lectures were carried out at all 19 junior high schools in Okazaki city, Aichi prefecture, Japan, between 2009 and 2011. One Muscle Sensor was donated to each junior high school in Okazaki in hope it could help teachers teach science classes, even after the on-site lecture by us.

In order to see how the students' neuroscience understanding had changed, a questionnaire was carried out at Johoku Junior High School, Okazaki city, Aichi prefecture, Japan. The questionnaire covered topics the students should have learned in their science class during their second year (Table 1). After the ordinal textbook-based science classes were taken, the same questionnaire was given out to second-year students after (with) or before (without) the on-site hands-on experience by the Muscle Sensor. The results were compared to see whether their understanding had changed. The results are shown in Table 2. The results from both questionnaires show a significant rise in understanding of the basics of neuroscience by the on-site hands-on experiences.

Table 1
Questionnaire questions.

(Q1) What shape are nerves of motor neurons like?
(1) Donut shaped
(2) Rectangular shaped
(3) String shaped
(4) I don't know
The correct answer is (3).

(Q2) What information runs through nerves of motor neurons?
(1) Chemical signals created by chemical materials
(2) Electrical signals created by a potential difference
(3) Mechanical signals created by applying a force that bends out or shrinks cells
(4) I don't know
The correct answer is (2).

4. Discussion

The fundamental knowledge of neuroscience is not as widely known throughout society as hoped in Japan, despite the MEXT junior high school curriculum. A likely cause is because most of

Table 2
Percentages of questions in Table 1 answered correctly.

	Q1 (%)	Q2 (%)
Before (Without) hands-on experience ($n = 100$ students)	17.0	31.0
After (With) hands-on experience ($n = 100$ students)	62.0	65.0

the lectures on neuroscience are confined to textbook work in the classroom. As shown above, the hands-on experience by the Muscle Sensor pave the way for a better understanding of neuroscience research such as brain–machine-interface.

On the other hand, today, the majority of scientific research is funded by tax money, and therefore scientists have the responsibility to inform the public, their funders, on the results about their researches (Koizumi, 2009). In the future, we will give on-site lectures with hands-on experience by the Muscle Sensor to elementary school, junior high school, and high school students across Japan in order to be able to share basic neuroscience knowledge and advanced neuroscience research results with the public. These on-site lecture activities by neuroscientists should be encouraged and supported in Japan (Koizumi et al., 2013).

In the other countries as well as in Japan, the neuroscientists world-wide provide hands-on experience of neuroscience to students and teachers in the Brain Awareness Campaign, which is launched by The Dana Alliance for Brain Initiatives. In addition, Society for Neuroscience published the Brain Facts, an English textbook of basic neuroscience for secondary school teachers and students (BrainFacts.org, 2012).

According to the results of Table 2, still approximately 40% of student answered wrong even after the on-site lecture. Not only hands-on experience but the combination of hands-on experience and textbook knowledge was essential to learn the basics of neuroscience. The Japanese neuroscientists and their society need to make a comprehensive Japanese neuroscience textbook for junior high and high school students like the Brain Facts published by Society for Neuroscience.

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